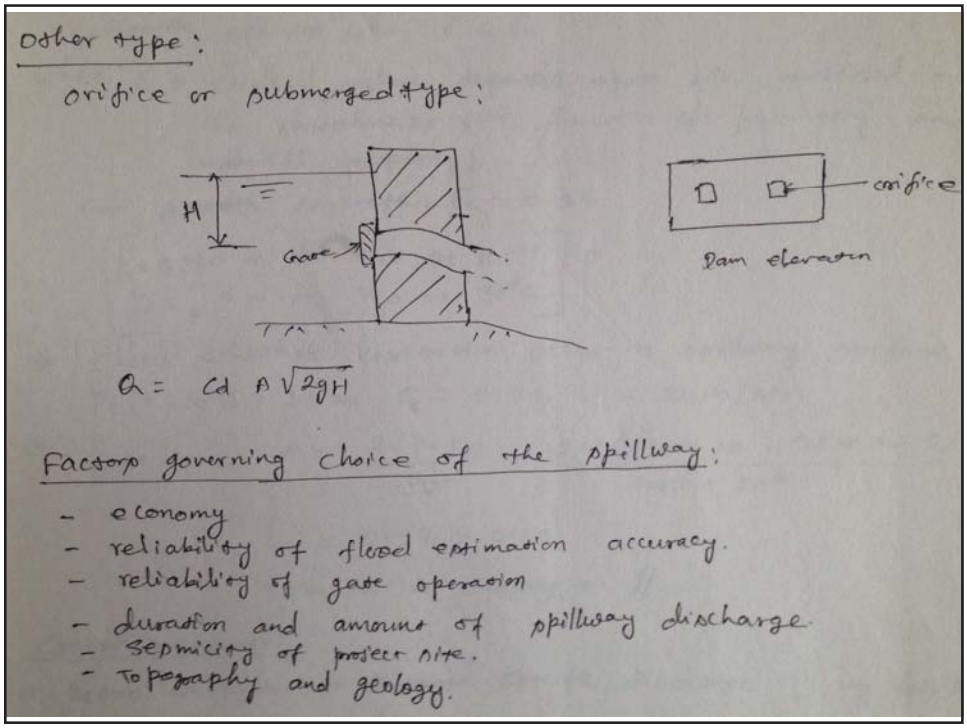


Spillway

A Spillway is a channel or passageway through which flood/surplus water escapes or release safely from a reservoir or dam. They are provided for all dams as a safety measure against overtopping and the consequent damages and failure. It acts as a safety value for the dam. The spillway must be hydro-dynamically & structurally safe.

Spillways are basically dam appurtenances ensuring a safe passage of floods from the reservoir into the downstream river reach. The spillway design depends primarily on the design flood, dam type and location, and reservoir size and operation.

The purpose/function of the spillway is to pass flood water, and in particular the design flood, safely downstream when the reservoir is overflowing

Components of Spillway

It has two principal components: the controlling spillweir and the spillway channel, the purpose of the latter being to conduct flood flows safely downstream of the dam. The latter may incorporate a stilling basin or other energy-dissipating devices. The spillway capacity must safely accommodate the maximum design flood, the spillweir level dictating the maximum retention level of the dam, i.e. the normal maximum water level (NWL).

Essentials of A Spillway

The essentials of a spillway are

- **adequate capacity** to serve as **moderation of floods.**
- While conveying the excess flows downstream the tail water maintained is such that the **purpose and protection of dam and its appurtenant work are fully ensured.**
- Providing **safe & regulated release of the surplus** water in excess of the reservoir capacity.

Requirements:

- Should able to pass the designed flood without raising the reservoir level above H.F.L.
- Should provide structural stability to the dam under all conditions of flood.
- Section of spillway should be economical.
- Operation of spillway should be efficient.

LOCATION OF SPILLWAY

- Generally, the spillways are provided at the following places
- Spillways may be provided within the body of the dam.
- Spillways may sometimes be provided at one side or both sides of the dam.
- Sometimes by-pass spillway is provided which is completely separate from the dam.

CLASSIFICATION OF SPILLWAYS

I. According to the most prominent feature

- Overflow spillway
- Chute spillway
- Side channel spillway
- Saddle spillway
- Emergency spillway
- Shaft spillway
- Siphon spillway
- Stepped spillway

II. According to Function

- A. Service spillway
- B. Auxiliary spillway
- C. Fuse plug or emergency spillway

III. According to Control Structure

- A. Gated spillway
- B. Ungated spillway
- C. Orifice of sluice spillway

Overflow spillway:

- Also called ogee-shaped (S-shaped) spillways.
- This type of spillways allows the passage of the flood wave over its crest (which is S-shaped).
- Widely used on Gravity dams, Arch dams, and Buttress dams.
- Reduce the impact of water at downstream.
- Reduce scouring.
- Used for small concrete dams.

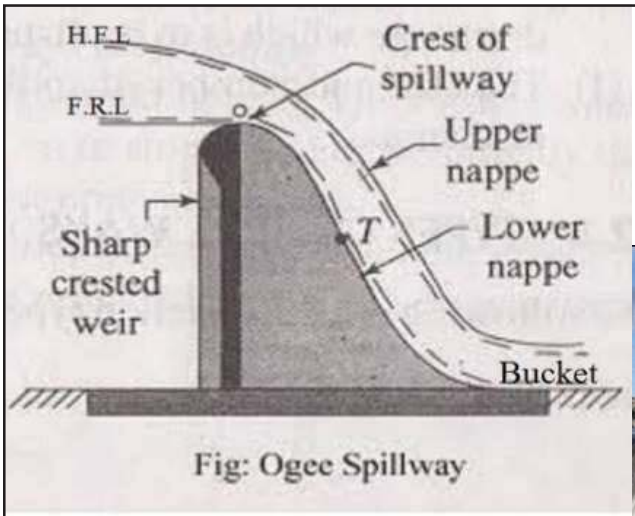
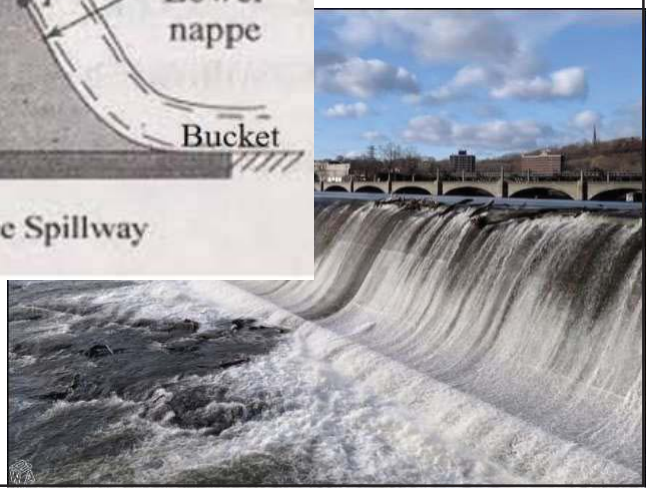


Fig: Ogee Spillway



Chute spillway:

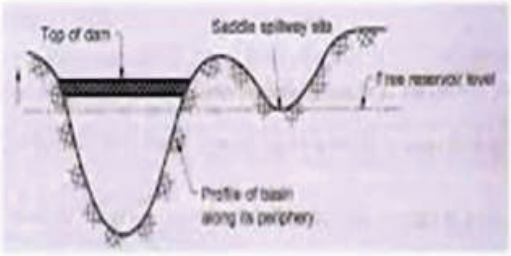
- Discharge is conveyed from the reservoir to the d/s through an open channel.
- Profile is influenced by site topography.
- Used for earth fill dam
- Crest of spillway is kept normal to its centre line.

Side channel spillway:

- It is used when dam is not rigid and it is undesirable to pass flood water over the dam.
- After passing crossing over the spillway rest, water flows parallel to the crest.

Saddle spillway:

- Constructed when other types of spillways are not favourable.
- There may be some natural depressions on the periphery of the reservoir basin away from the dam.



Emergency spillway:

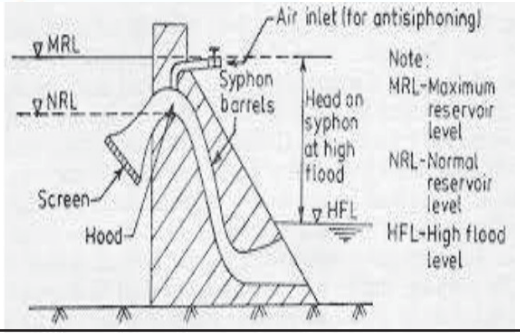
- Rarely used.
- Extra spillways provided on a project in case of emergency.
- Used to convey frequently occurring outflow rates.

Shaft spillway:

- The shape is just like a funnel.
- Water drops through a vertical shaft to a horizontal conduit that conveys the water past the dam.
- Also called as glory hole spillway.

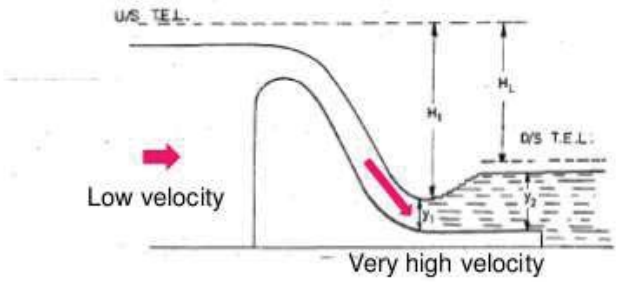
Siphon spillway:

- Designed by the principle of siphon.
- When water rises over FRL then water start spilling.
- There is an air vent for removing the entrapped pressure from the water.



ENERGY DISSIPATION

For a given discharge intensity over a spillway, the depth y_1 is equal to q/V_1; and V_1 is determined by the drop H_1, being equal to $\sqrt{2gH_1}$.



$V_1=(2gH_1)^{0.5}$

$y_1=q/V_1$

Dissipation of the kinetic energy generated at the base of a spillway is essential for bringing the flow into the downstream river to the normal—almost pre-dam— condition in as short of a distance as possible.

This is necessary, not only to protect the riverbed and banks from erosion, but also to ensure that the dam itself and adjoining structures like powerhouse, canal, etc. are not undermined by the high velocity turbulent flow.

ENERGY DISSIPATION

CLASSIFICATION

1. Based on hydraulic action: Turbulence and internal friction as in hydraulic jump stilling basins, roller buckets, and impact and pool diffusion as with ski jump buckets and plunge pools.

2. Based on the mode of dissipation: Horizontal as in the hydraulic jump, vertical as with ski jump buckets/free jets, and oblique as with spatial and cross flows. The vertical dissipation may be in the downward direction as with free jets and plunge pools and in upward direction as with roller buckets.

3. Based on geometry or form of the main flow: Situations involving sudden expansion, contraction, counter acting flows, impact, etc.

4. Based on the geometry or form of the structure: Stilling basin employs hydraulic jump with or without appurtenances like chute blocks, baffle piers, etc. Buckets (ski jump or flip buckets) include special shapes like serrated, dentated buckets, and roller buckets that are either solid roller bucket or slotted buckets.

ENERGY DISSIPATION

PRINICIPAL TYPES OF ENERGY DISSIPATORS

The energy dissipators for spillways can be grouped under the following five categories:

1. Hydraulic jump stilling basins
2. Free jets and trajectory buckets
3. Roller buckets
4. Dissipation by spatial hydraulic jump
5. Impact type energy dissipators

ENERGY DISSIPATION

ANALYSIS OF PARAMETERS

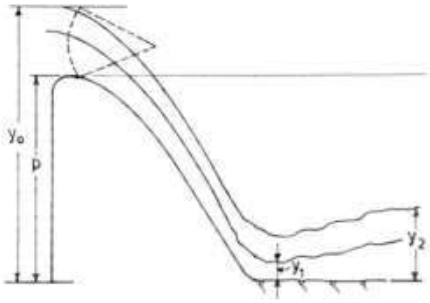


Figure 1 Key parameters in energy dissipation. (Rudavsky, 1976)

① Headwater rating curve
② Energy line for head water
③ Tail water rating curve
④ Energy line for tail water

Energy equation:

$$y_o + \frac{V_o^2}{2g} = y_1 + \frac{V_2^2}{2g} = y_2 + \frac{V_2^2}{2g} + \Delta E$$

ΔE= Energy dissipation between u/s and d/s

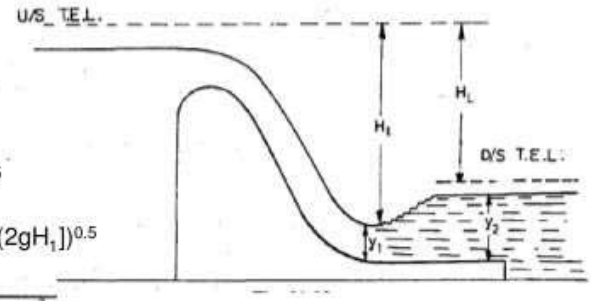
Mass conservation:

$Q_1=Q_2=Q_3$

ENERGY DISSIPATION

In case of hydraulic jump at the d/s

For a given discharge intensity over a spillway, the depth y_1 is equal to q/V_1 ; and V_1 is determined by the drop H_1, being equal to $\sqrt{2gH_1}$.



$V_1=(2gH_1)^{0.5}$

$y_1=q/V_1$

Thus, $q/y_1=(2gH_1])^{0.5}$

$$y_2=-\frac{y_1}{2}+\sqrt{\frac{y_1^2}{4}+\frac{2q^2}{gy_1}}$$

Assumption of Horizontal bed !!!

Energy dissipation

$$\Delta E==\left(y_2+\frac{V_2^2}{2g}\right)-\left(y_1+\frac{V_2^2}{2g}\right)$$

ENERGY DISSIPATION

Hence, for a given discharge intensity and given height of spillway, y_1 is fixed and thus y_2 (required for the formation of hydraulic jump) is also fixed.

But the availability of a depth equal to y_2 in the channel on the *d/s* cannot be guaranteed as it depends upon the tail water level, which depends upon the hydraulic dimensions and slope of the river channel at d/s.

The problem should, therefore, be analyzed before any solution can be found by plotting the following curves:

Tail Water Curve (TW Curve): A graph plotted between *q* and tail water depth,

Jump Height Curve (JH Curve) *also called* ***y_2 curve****:* A curve plotted on the same graph, between *q* and y_2,

ENERGY DISSIPATION

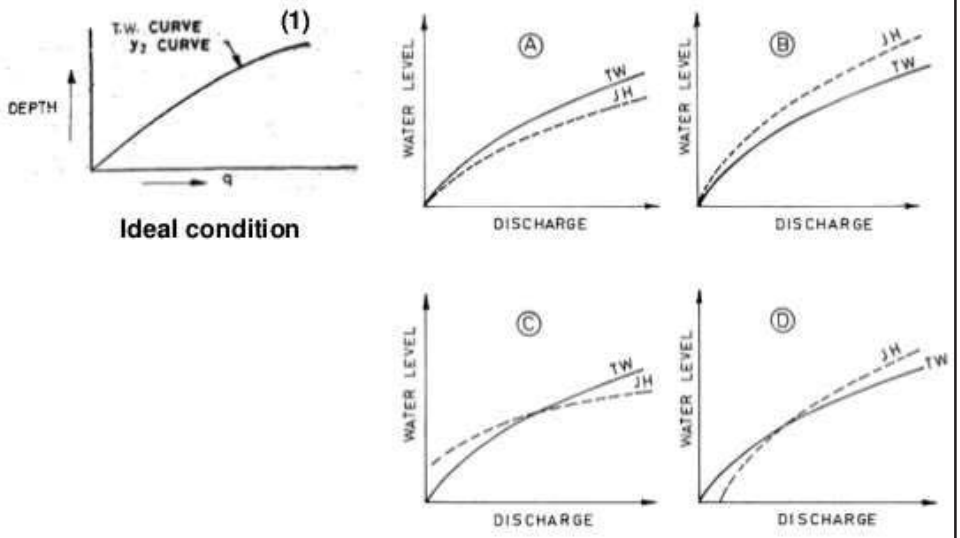


Figure 2 Jump height and tail water rating curves.

ENERGY DISSIPATION

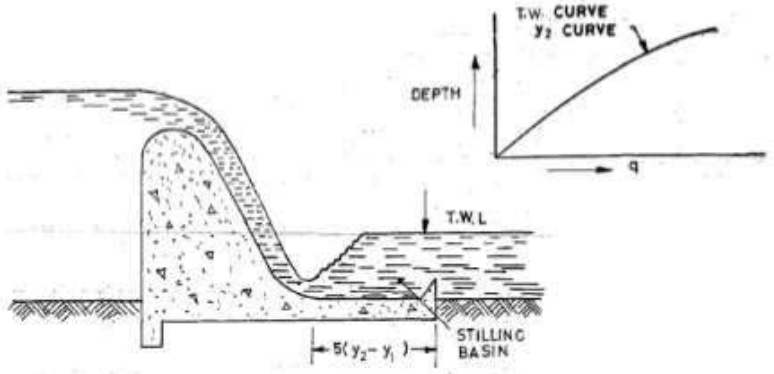
Table 1 Choice of Energy Dissipator Based on Analysis of JH and TW Rating Curves

Case	Situation	Suggested arrangement
A	TW curve is above the JH curve for all the discharges	Horizontal apron if $1 < y_t/y_2 < 1.1$ and sloping apron/roller bucket if $y_t/y_2 > 1.1$
B	TW curve is below the JH curve for all the discharges	Flip bucket
C	TW curve is below the JH curve for lower discharges and above the JH curve for higher discharges	Sloping-cum-horizontal apron such that the jump forms on the horizontal portion for low discharges and on the sloping portion for high discharges
D	TW curve is above the JH curve for lower discharges and below the JH curve for higher discharges	A combination energy dissipator performing as a hydraulic jump apron for low discharges and flip bucket for high discharges

ENERGY DISSIPATION

(1). When TW curve coincides with y_2 curve

This is the most ideal condition for jump formation. The hydraulic jump will form at the toe of the spillway at all discharges. In such a case, a simple concrete apron of length equivalent to length of jump (e.g.,5 [y_2 - y_1]) is generally sufficient to provide protection



Simple horizontal apron.

ENERGY DISSIPATION

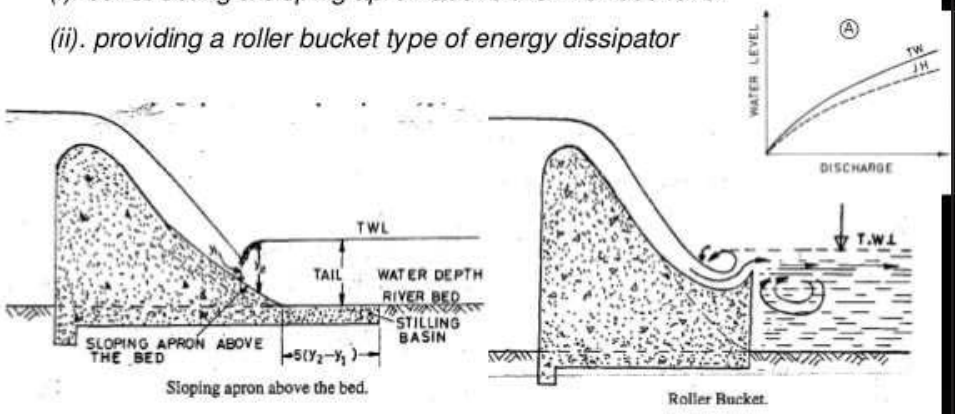
(A). When TW curve is above the y_2 curve

When y_2 is always below the tail water, the jump forming at toe will be drowned out by the· tail water, and little energy will be dissipated.

The problem can be solved by:

(i). constructing a sloping apron above the river bed level

(ii). providing a roller bucket type of energy dissipator

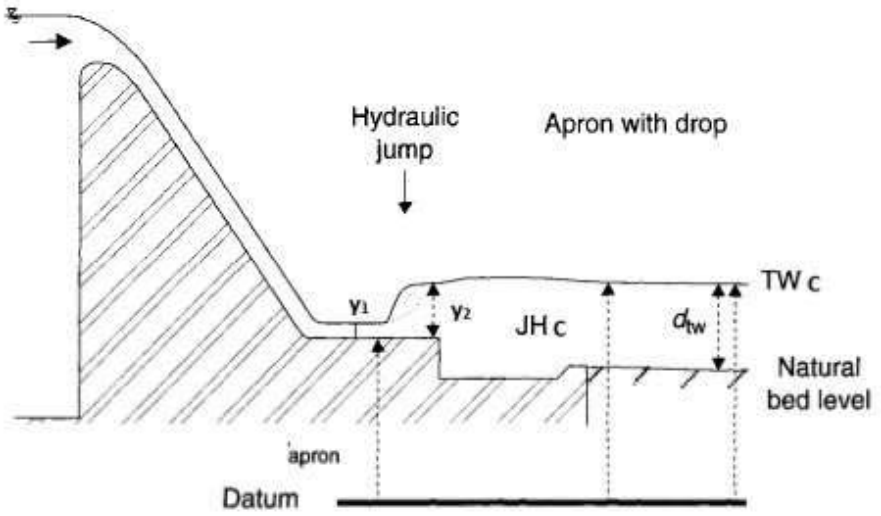


Sloping apron above the bed.

Roller Bucket.

ENERGY DISSIPATION

iii. Providing a higher apron level followed by a drop

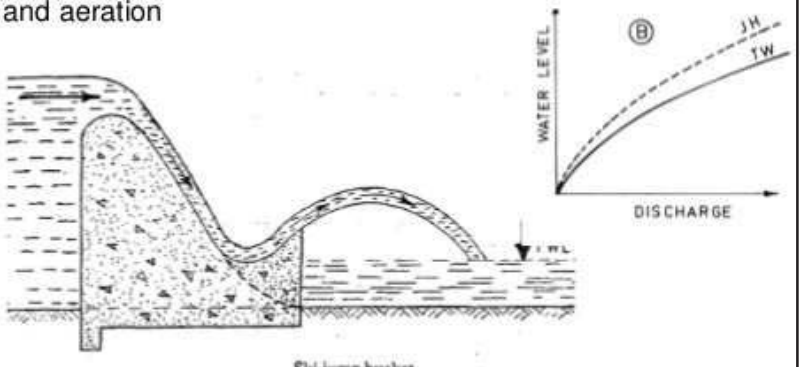


ENERGY DISSIPATION

(B). When TW curve is below the y_2 curve

When the tail water depth is insufficient or low at all discharges, the following solution can be applied:

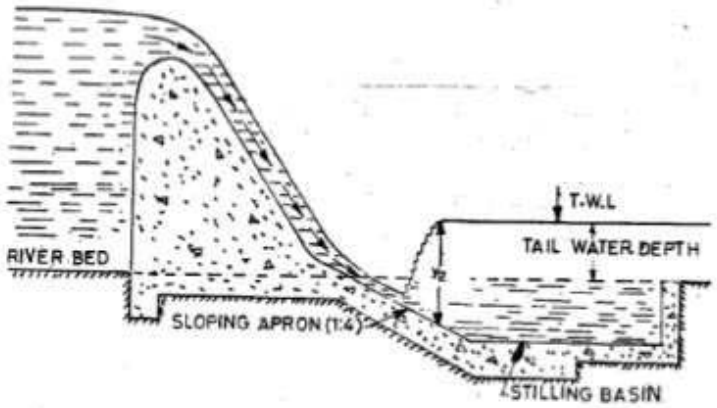
(i). Ski jump bucket type: This type of energy dissipator requires sound and rocky river bed, because a part of the energy dissipation takes place by impact, although some of the energy is dissipated in air by diffusion and aeration



Ski jump bucket.

ENERGY DISSIPATION

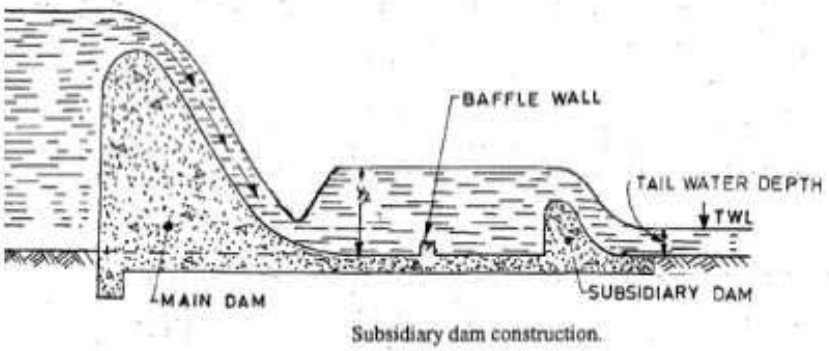
(ii). Providing of a sloping apron as below the river bed



Sloping apron below the bed.

ENERGY DISSIPATION

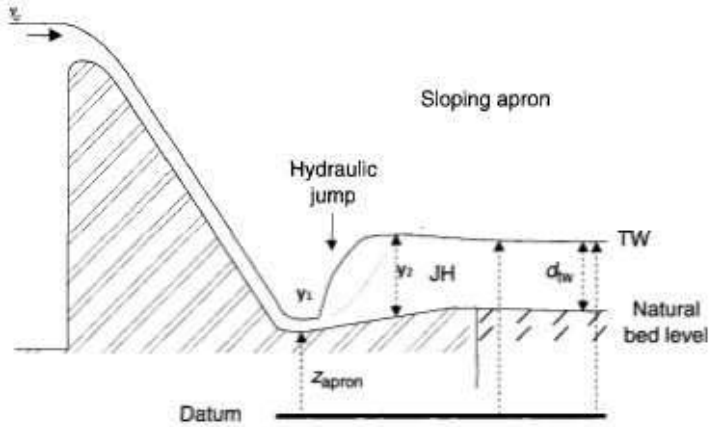
(iii). Constructing a subsidiary dam below the main dam



Subsidiary dam construction.

ENERGY DISSIPATION

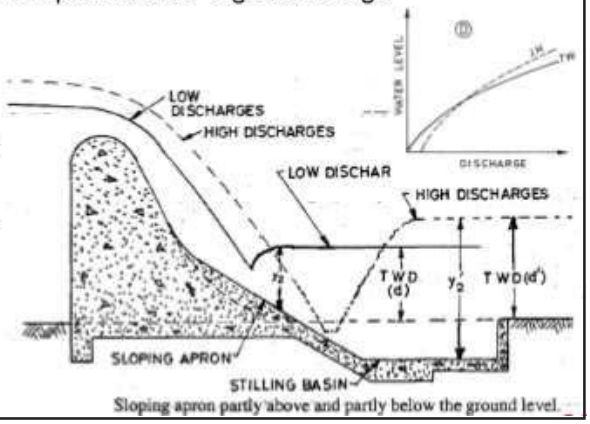
(iv) Providing upward slope



ENERGY DISSIPATION

(D). When TW curve is above the y_2 curve at low discharges and below the y_2 curve at high discharges: In this case, at low discharges, the jump will be drowned and at high discharges, tail water depth is insufficient. *The following solutions can be applied by:*
(i). Providing a sloping apron partly above and partly below the river bed
(ii). A combination of energy dissipator performing as a hydraulic jump apron for low discharges and flip bucket for high discharges

At low discharges, the jump will form on the apron above the river bed.
Similarly, at high discharges, the jump will form on the apron below the river bed

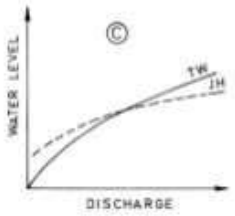


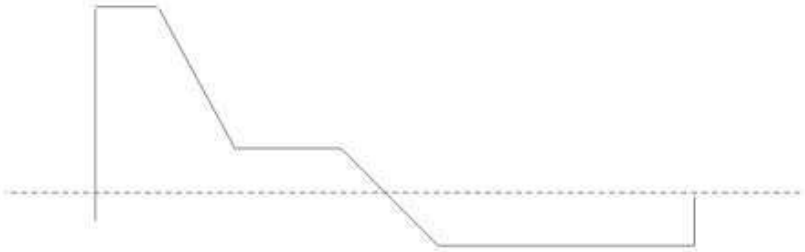
Sloping apron partly above and partly below the ground level.

ENERGY DISSIPATION

(C). When TW curve is below the y_2 curve at low discharges and above the y_2 curve at high discharges (inverse of case D)

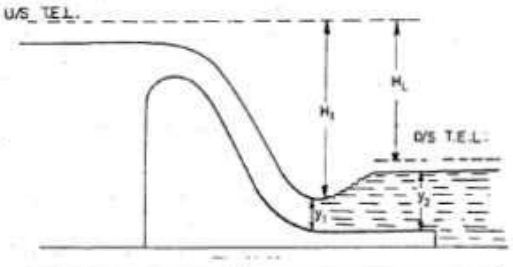
The following solutions can be applied:
(i). Sloping-cum-horizontal apron such that the jump forms on the horizontal portion for low discharges and on the sloping portion for high discharges





ENERGY DISSIPATION IN HYDRAULIC JUMP

Hydraulic jump can be used as Energy Dissipator



F_1	% loss of energy
2.5	17
4.5	45
9.0	70
14.0	80
20.0	85

$V_1=(2gH_1)^{0.5}$
$y_1=q/V_1$
Thus, $q/y_1=(2gH_1])^{0.5}$

$$y_2/y_1=\frac{1}{2}\left[\sqrt{1+8F_1^2}-1\right]$$

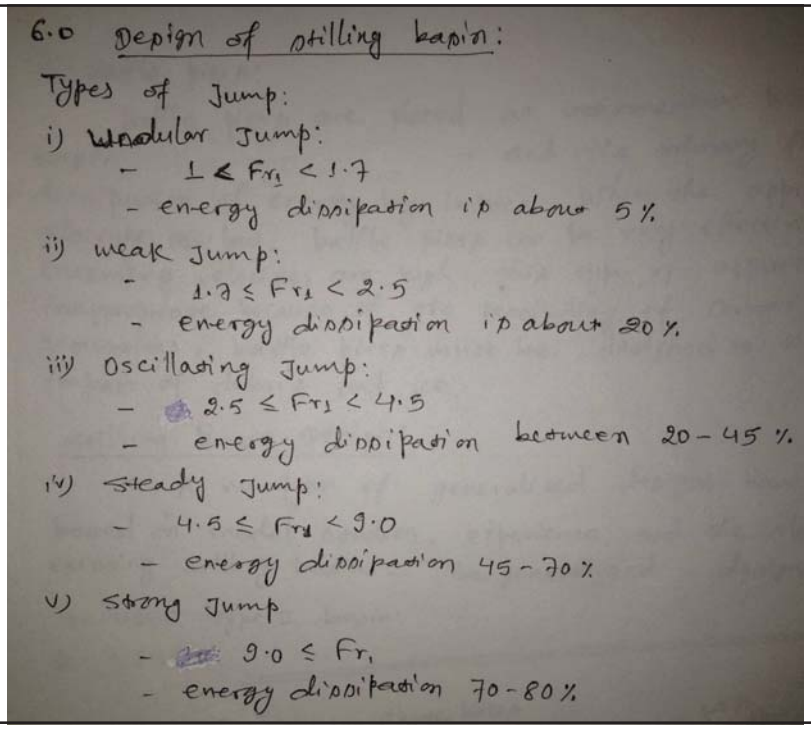
$$V=q/y$$

$$\Delta E=\left(y_2+\frac{V_2^2}{2g}\right)-\left(y_1+\frac{V_2^2}{2g}\right)$$

$$\Delta E=\left(\frac{y_2-y_1}{4y_1y_2}\right)$$

$$F=\left(\frac{V}{\sqrt{gy}}\right)$$

However, the real problem in the design of stilling basins, is not the absolute dissipation of energy, but is the dissipation of this energy in as short a length as possible.



6.0 Design of stilling basin:

Types of Jump:

i) Undular Jump:
- $1 \leq Fr_1 < 1.7$
- energy dissipation is about 5%

ii) weak Jump:
- $1.7 \leq Fr_1 < 2.5$
- energy dissipation is about 20%

iii) Oscillating Jump:
- $2.5 \leq Fr_1 < 4.5$
- energy dissipation between 20 - 45 %

iv) Steady Jump:
- $4.5 \leq Fr_1 < 9.0$
- energy dissipation 45 - 70 %

v) Strong Jump
- $9.0 \leq Fr_1$
- energy dissipation 70 - 80 %

STILLING BASIN

- In general, a stilling basin may be defined, as a structure in which the energy dissipating action is confined.
- If the phenomenon of hydraulic jump is basically used for dissipating this energy; it may be called a *hydraulic jump type of stilling basin*.
- The auxiliary devices may be used as additional measures for controlling the jump, etc.
- Stilling basins are placed at the ends of dam spillways and at the ends of steep-sloped canal sections where elevation change has generated high kinetic energy.
- Stilling basin come in a variety of types and can either contain a straight drop to a lower elevation or an inclined chute
- **Inclined chutes are the most common design for stilling basins and the most used inclined chutes are: USBR Stilling Basins Type II-IV, SAF Stilling Basins**

STILLING BASIN

In practice, the following types are highly recommended:

- USBR Type II basin for large structures and $Fr > 4.5$;
- USBR Type III basin and the SAF basin for small structures;
- USBR Type IV basin for oscillating jump flow conditions

The designs are selected based on the Froude Number of the flow and the flow velocity:

$$Fr_1 = \left(\frac{V_1}{\sqrt{g y_1}} \right)$$

$$V_1 = \frac{q}{y_1}$$

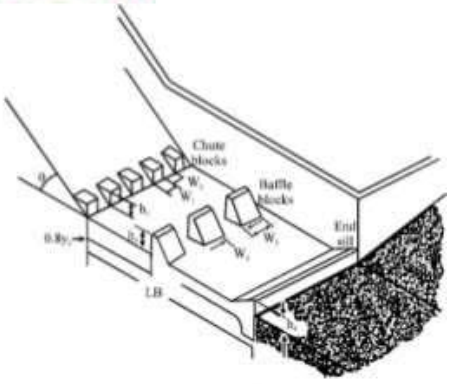
STANDARD STILLING BASINS

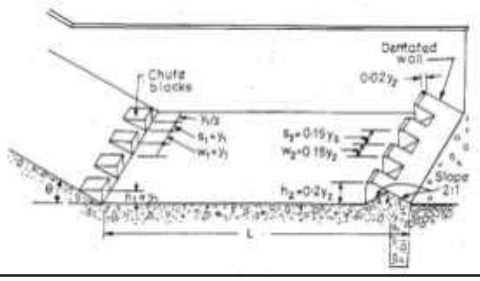
Elements of Stilling Basin

Chute blocks

Baffle blocks

End sill or Dentated Sill





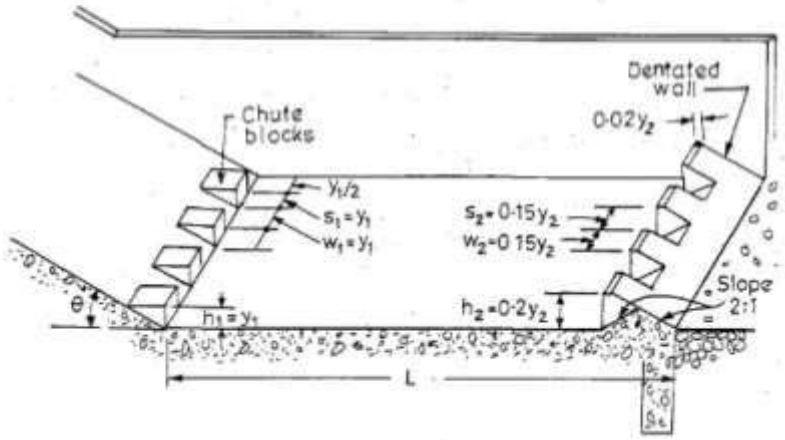
STANDARD STILLING BASINS

- **Chute blocks** -concrete blocks built into the inclined sections of the spillway. These features are commonly placed at the head of the stilling basin to create turbulence prior to the hydraulic jump
- **Baffle blocks** -freestanding concrete blocks built in the main basin. These blocks are only used for flows <20m/s due to the high force they are subjected to and the potential for cavitation
- **End sills** -a built-up lip at the tail of the basin, with or without blocks. The sill height has the most significant impact on energy dissipation and taller sills are used to reduce the overall length of the stilling basin

STANDARD STILLING BASINS

USBR Stilling Basin Type II

$Fr_1 > 4.5$

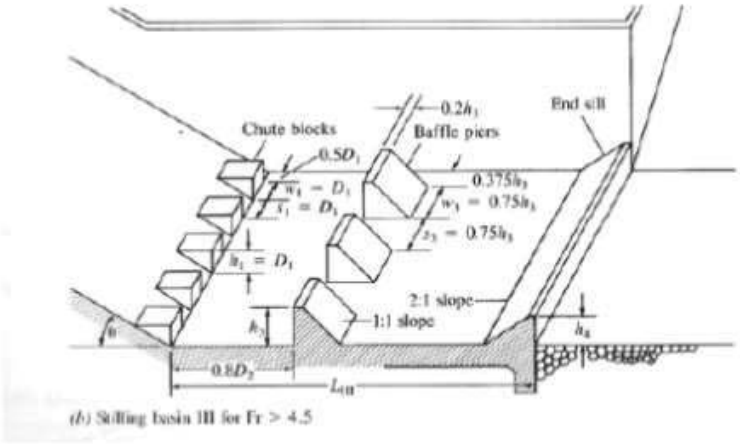


U.S.B.R. Stilling basin II ($F_1 > 4.5$).

STANDARD STILLING BASINS

USBR Stilling Basin Type III

Fr_1 > 4.5 & V<18m/s



(b) Stilling basin III for Fr > 4.5

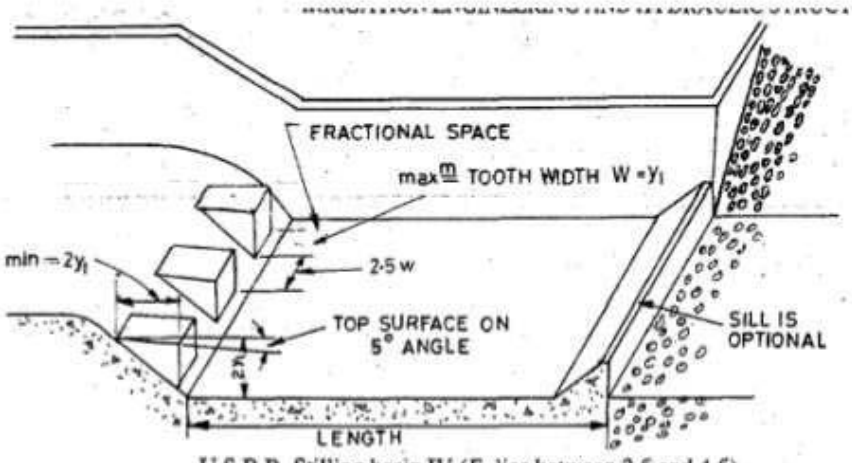
$D_1 = y_1$

$$h_3 = y_1[1.30 + 0.164(Fr_1 - 4.0)]$$
$$h_4 = y_1[1.25 + 0.056(Fr_1 - 4.0)]$$

STANDARD STILLING BASINS

USBR Stilling Basin Type IV

Fr_1=2.5-4.5

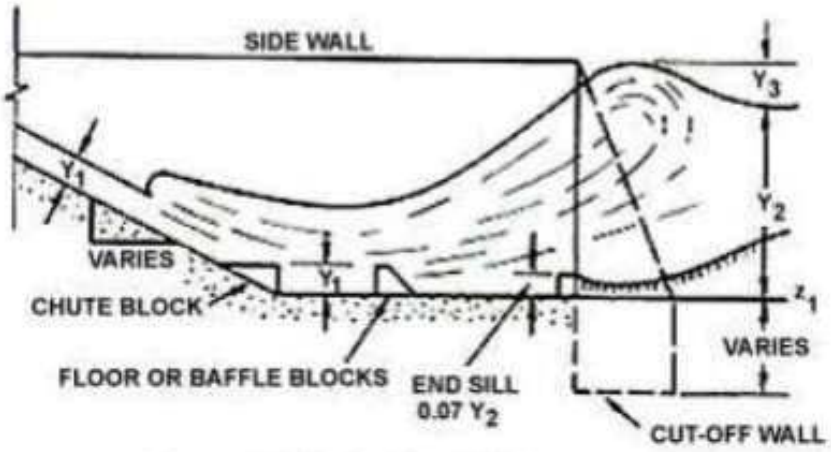


U.S.B.R. Stilling basin IV (F_1 lies between 2.5 and 4.5).

STANDARD STILLING BASINS

Saint Anthony Falls

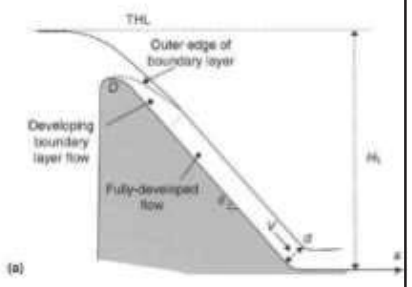
Effective for Fr_1= 1.7 and 17



STANDARD STILLING BASINS

Summary

Name (1)	Application (2)	Flow conditions (3)
USBR Type II	Large structures	$Fr > 4.5$ $q < 46.5\ m^2/s$ $H_1 < 61\ m$ Basin length ~ $4.4L_{conj}$
USBR Type III	Small structures	$Fr > 4.5$ $q < 18.6\ m^2/s$ $V < 15–18.3\ m/s$ Basin length ~ $2.8L_{conj}$
USBR Type IV	For oscillating jumps	$2.5 < Fr < 4.5$ Basin length ~ $6L_{conj}$
SAF	Small structures	$1.7 < Fr < 17$ Basin length = $4.5L_{conj}Fr^{-0.76}$
USACE		Basin length > $4L_{conj}$



$d=y_1$

$dconj=y_2$

ENERGY DISSIPATION

DEFLECTOR BUCKETS

Sometimes it is convenient to direct spillway into the river without passing through a stilling basin. This is accomplished with a *deflector bucket* designed so that the jet strikes the riverbed a safe distance from the spillway and dam. This type of spillway is often called a *flip bucket* or *ski jump* spillway.

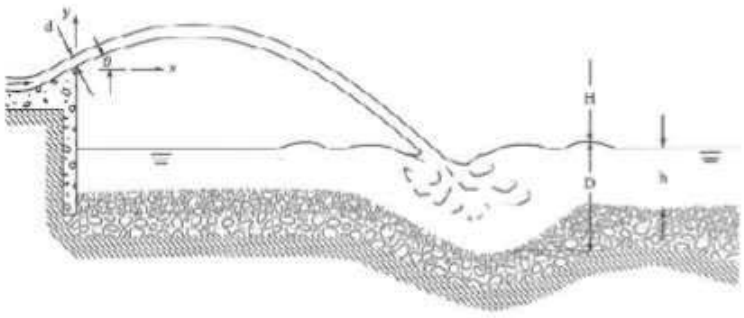


Figure 7.16. Definition sketch for reflector bucket and plunge pool

ENERGY DISSIPATION

The trajectory of the jump

$$y = x\tan\theta - \frac{x^2}{4Cos^2\theta(h_v + d)}$$

Where,

h_v = Velocity head

d = Thickness of the jump

When the free jet discharging from the deflection bucket falls into an erodible riverbed, a plunge pool is eroded to a depth, D, given by:

$$D = 1.90H^{0.225}q^{0.54}$$

where

D = Depth of scour measured from the tailwater (meters)
q = Discharge per unit width (m^3/sec/m)
H = Drop in elevation from reservoir water surface to tailwater (meters)